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BUILDINGS EFFECTS ON THERMAL STRATIFICATION DURING THE MUST TRIALS

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1. INTRODUCTION

The MUST (Mock Urban Setting Test) trials were conducted on the "Horizontal Grid" at the Dugway Proving Ground in Utah's west desert area (September 2001). This was a multi-organizational effort to gain scientific understanding for improved dispersion modeling in urban areas. During the MUST trials, meteorological and concentration measurements were throughout a 12 x 10 array of shipping containers (each 12.2 m long, 2.6 m wide, 2.6 m high) that were fully immersed in a high Reynolds number, real atmospheric boundary layer (see Biltoft (2001) and Biltoft et al. (2002) for details of the experimental site). For a normal incident flow angle, the inner buildings were typically in an isolated roughness regime. The data presented here were taken from the evening transition period (~17:30 LST) through the early morning (~8:00 LST) on September 24, 2001.

Previous investigations have suggested that within a building array, mechanically generated turbulence dominates over buoyancy and destroys the upstream stable stratification (e.g. Steggel & Castro, 1998). The high instrument density of the MUST configuration provided an excellent forum for investigating this notion.

2. MEASUREMENTS AND INSTRUMENTS

In an effort to better understand the interplay between mechanically generated turbulence and buoyancy in a building array (in a high Reynolds number flow), measurements of mean and fluctuating components of the velocity and temperature were made within the first row of the array with five 3D Campbell Scientific sonic anemometers and five fine-wire thermocouples (20 Hz sampling rate). The instruments were mounted on a 5 meter tower at heights of z = 0.6 m, 1.0 m, 1.8 m, 2.6 m, 3.7 m. For southerly winds, the tower was located 4.95 m behind the

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first building along its centerline. Away from the array, near ground measurements of temperature were made with Lumitherm quartz thermometers at z = 0.0, 0.01, 0.05, 0.10, 0.25, 0.5, 1.0 and 2.0 m to represent the ambient stratification. Mean velocity and turbulence quantities were measured upstream at z = 1.6 m with an Applied Technologies, Inc Sx 3D ultrasonic anemometer (10 Hz sampling rate). Vertical profiles of temperature, relative humidity, wind speed and wind direction outside of the array were obtained up to ~1000 m using a Vaisala tethered meteorological balloon.
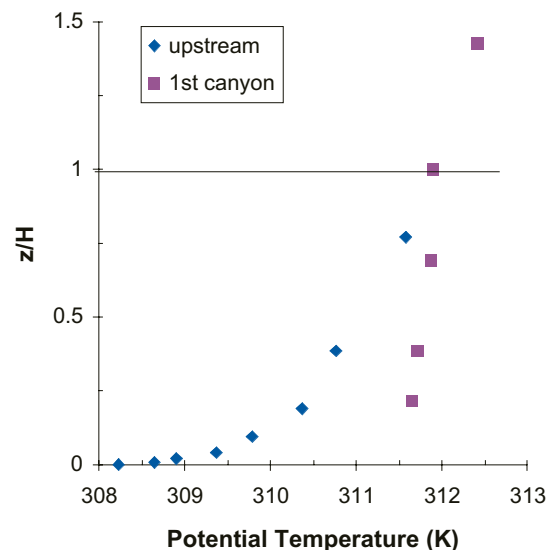
3. RESULTS

Fig. 1: Ten minute averages of potential temperature profiles upstream and within the first canyon at 19:50 Local Daylight time (LDT) during MUST.

The clear skies and weak synoptic conditions that prevailed during MUST resulted in trials that were largely conducted under stably-stratified conditions outside of the building array. Figure 1 shows vertical profiles of potential temperature

upstream of the building array and within the first canyon. Upstream of the array, the potential temperature data indicate the existence of strong stable stratification near the surface before sunset (sunset was 19:25 LDT). Upstream balloon profiles showed that as early as 19:00 LDT, a stably stratified layer (buoyancy frequen-cy, N~0.05 s^{-1}) existed up to about 40 m.

Figure 1 contains several interesting features associated with the canyon flow field. The wake is slightly stably stratified, but nearly neutral at the time shown. It is, however, much warmer than the ambient air at the same level upstream. This warm thermal plume is likely a result of heat being transferred from the large steel containers. The thermal plume lasts long into the night; as a result, the temperatures within the array remain warmer than the upstream flow and the flow at rooftop level. As cooling continues throughout the night the stability within the canyon increases and becomes strongly stable ($N > 0.05s^{-1}$). This stable stratification periodically breaks down (on time scales ~ 30 minutes) and rebuilds throughout the night becoming neutral at times.

Figure 2 is a plot of the normalized local friction velocity u_*, as function of non-dimensional height within and above the street canyon, where

$$u_*^2 = \left(\left\langle \overline{u'w'} \right\rangle^2 + \left\langle \overline{v'w'} \right\rangle^2 \right)^{1/2}$$

is a measure of the turbulent shear stress. The local friction velocity has been normalized by the friction velocity measured at z=1.4H. The turbulent stress is shown over a range of stabilities (-0.012<Ri<0.060). Several features are evident: (1) the height of maximum turbulent shear stress appears to drop with increasing stability from z/H>1.4 in the unstable case to z/H~1 in the more stable cases; (2) The ratio of the maximum stress to the stress at 1.4H increases with stability; (3) As a result of (1) the stress gradients (responsible for turbulent transport) within the canopy increase. It appears that the strong stable stratification above the buildings is confining most of the turbulence to within the canopy.

4. SUMMARY

Several interesting features associated with flow in the first canyon of the array under stable atmospheric conditions (for the night analyzed) have been identified, including: the existence of
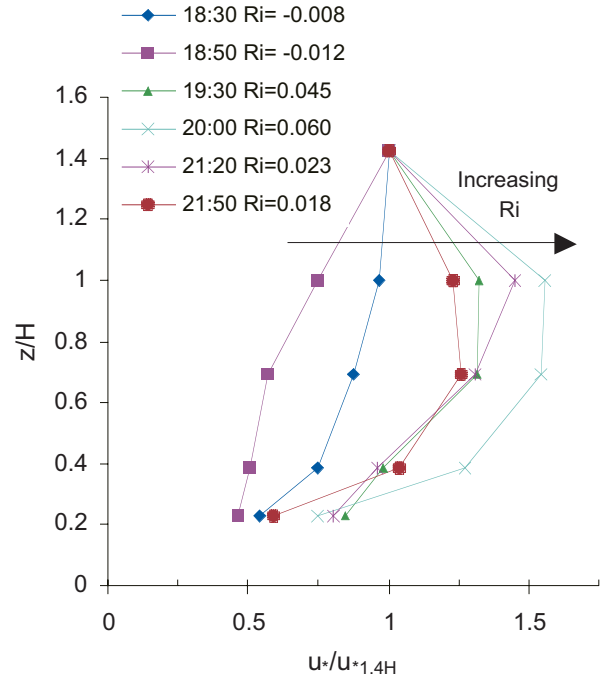

Fig. 2: Local friction velocity normalized by the friction velocity above the building level (z = 1.4H) as function of gradient Richardson number (10 min. averaging time).

a persistent warm thermal plume in the wake of the building and a well-mixed wake with strong stable stratification above the building height associated with the upstream flow. During the nighttime period studied, however, the air within the canyon is stably stratified. This stable-stratification effects the turbulent stress distribution within the canopy by lowering the height of the peak shear stress level.

5. REFERENCES

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